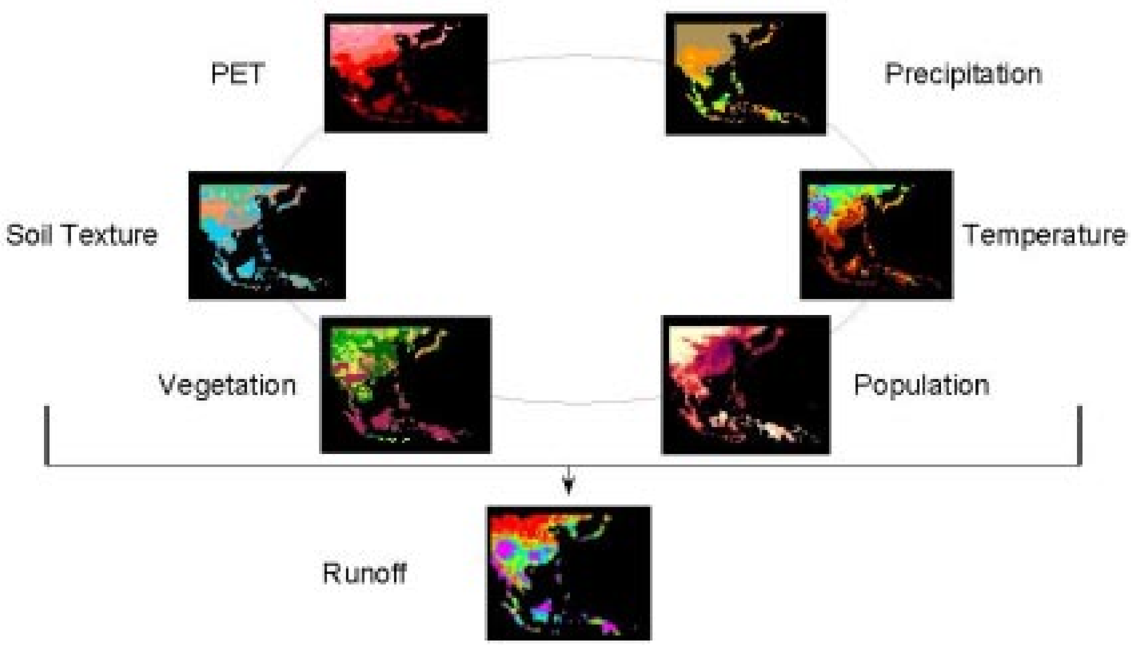
SOUTHEAST ASIA
INTEGRATED REGIONAL MODEL

NAGA Version 1 (~ 100 km)



RIVER BASIN INPUTS TO THE COASTAL ZONE
(*SEA/BASINS*)

Proceeding of the Initial Orientation Workshop sponsored by:

APN Asia-Pacific Network for Global Change Research

START HDP • IGBP • WCRP

Global Change System for Analysis, Research and Training

Proceeding of the Initial Orientation Workshop

SOUTHEAST ASIA
INTEGRATED REGIONAL MODEL:

RIVER BASIN INPUTS
TO THE COASTAL ZONES
(*SEA/BASINS*)

Toh Sang Khongjiam Hotel, Ubon Rachathani, Thailand
14-17 July 1998

Edited by

Jeffrey E. Richey
Anond Snidvongs

SOUTHEAST ASIA
START
HDP • IGBP • WCRP
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Front cover:

Regional Hydrological Model for Southeast Asia (NAGA) Version 1 (1 degree resolution)

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Table of Content

Acknowledgement

SEA/BASINS project was established as an extension of SARCS/WOTRO/LOICZ Southeast Asia Core Research which comprises of five study sites in Indonesia, Malaysia, Philippines, Thailand and Vietnam. In addition, SEA/BASINS will attempt to integrate activities of the three primary objectives of Southeast Asia START, which are IGBP/IHDP Land Use and Cover Changes (LUCC), IGBP Land-Ocean Interaction in Coastal Zone (LOICZ), and IGBP International Global Atmospheric Chemistry (IGAC). The main focus of SEA/BASINS is to develop a practical tool for planners/policy makers to support decision making involving global changes in the region.

Funding for the project has come from several sources. The hydrological and chemical models have been developed in Seattle, USA by a grant from the National Science Foundation. Additional regional data compilation at SEA START RC in Bangkok, as well as workshops and meetings among partners of the project has been funded by the Asia-Pacific Network for Global Change Research and the International START. USAID through the Associate Liaison Office for University Cooperation in Development, between Chulalongkorn University and the University of Washington, provide supports for information exchange system of the APEC Internet Collaboration Center. Lastly, a fellowship from BIOTROP/GCTE IC-SEA enabled a staff of SEA START RC to be trained at the University of Washington on modeling and GIS application.

List of Acronyms

ADB	Asian Development Bank
AET	Actual Evapotranspiration
AIM	Asia-Pacific Integrated Model
ALO	Association Liaison Office for University Cooperation in Development
APEC	Asia-Pacific Economic Cooperation
APN	Asia-Pacific Network for Global Change Research
APRN	Asia Pacific Regional Network
AVHRR	Advanced Very High Resolution Radiometer
BIOTROP	Regional Centre for Tropical Biology
BOD	Biochemical Oxygen Demand
CAMREX	Carbon in the Amazon River Experiment
CASA	Carnergie-Ames-Stanford Approach
CASM	Centre for Applied Simulation Modelling
CERL	Consortium of European Research Libraries
CIESIN	Consortium for International Earth Science Information Network
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
CU	Chulalongkorn University
DAAC	Distributed Active Archive Center
DBE	Drainage Basin Element
DCW	Digital Chart of the World
DEM	Digital Elevation Map
DOC	Dissolved Organic Carbon
ECMWF	European Centre for Medium-Range Weather Forecasts
EOS	Earth Observing System
EOSDIS	EOS Data Information System
EPA	Environmental Protection Agency
EROS	Earth Resources Observation Systems
ESRI	Environmental System Research Institute
ET	Evapotranspiration
FAO	Food and Agriculture Organization
FPAR	Fraction of Absorbed Photosynthetically Active Radiation
FTP	File Transfer Protocol
GCTE	Global Change and Terrestrial Ecosystems
GIS	Geographical Information System
GISS	Goddard Institute for Space Studies
GLORI	Global River Index
GRDC	Global Runoff Data Centre
GRID	Global Resource Information Database
GSFC	Goddard Space Flight Center
GTOPO30	Global Topographic Data 30 Arc Second
ICC	Internet Collaboration Center
IC-SEA	Impact Centre for Southeast Asia
IDL	Interactive Data Language
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimension Programme
IIASA	International Institute for Applied Systems Analysis
IOW	Initial Orientation Workshop
IRRI	International Rice Research Institute
IUCN	The World Conservation Union (International Union for Conservation of Nature and Natural Resources)

LAPAN	Lembaga Pemerbangan Dan Antariksa Nasional (Indonesian National Institute of Aeronautics and Space)
LOICZ	Land Ocean Interaction in Coastal Zone
LUCC	Land Use and Cover Changes
MRC	Mekong River Commission
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Production
NSF	National Science Foundation
PDR	People Democratic Republic
PET	Potential Evapotranspiration
PNG	Papua New Guinea
SARCS	Southeast Asia Regional Committee for START
SEA/BASINS	Southeast Asian Drainage Basins
SeaDAS	SeaWiFS Data Analysis System
SEA SPAN	Southeast Asian Science Policy Advisory Network
SEA START RC	Southeast Asia START Regional Center
SeaWIFS	Sea-viewing Wide Field-of-View Sensor
SM	Soil Moisture
START	Global Changes System for Analysis, Research and Training
UNDP	United Nation Development Programme
UNEP	United Nation Environmental Programme
UNESCO	United Nation Educational, Scientific and Cultural Organization
USAID	United States Agency for International Development
USGS	United States Geological Survey
UW	University of Washington
WOTRO	Wetenschappelijk Onderzoek van de Tropen (Netherlands Foundation for the Advancement of Tropical Research)
WWW	World Wide Web

1. Introduction and Review of Workshop Objectives.

The overall intention of *SEA/BASINS* is to build a multi-scale (time, space) integrated regional model *NAGA*[1] of changes in the water resources of Southeast Asia as a function of changes in landuse and land cover and regional climatology over river basins. The process is to use a core model structure as the integration platform to focus the knowledge of researchers and users throughout the region. The rationale and detailed approaches are discussed in the following sections. This Initial Orientation Workshop (IOW) was convened to launch the next phase of model development and application, as a planning activity of the core working group for the project, based at SARCS and the University of Washington.

The objectives of the IOW, as identified in planning and lead-in discussions, were to:

- Review the development of the different program elements that have come together to form the current backbone of *SEA/BASINS*
- Review the specific list of issues and questions that *SEA/BASINS* should be expected to address. (recognizing that the process is iterative)
- Review Version 1 of the model, and the developments expected for Version 2
- Work through the requirements for Version 2, and how to accomplish them (underlying science, tasks, personnel, networking, budgeting)
- Identify potential regional partners, and work out a strategy for including them
- Plan the November Partners Workshop (including lead-up and follow-up activities, potential participant list, exact objectives)

2. Project Background and Structure

2.1. Original Project Motivation

SEA/BASINS is a project of multiple threads.

The basic idea of integrated regional models representing multiple scale (in space and time) drainage basins is the backbone of the “CAMREX” Amazon basin project, a joint University of Washington (UW)/Brazil collaboration. CAMREX was started in 1982 and continues today, with support from the U.S. National Science Foundation and the NASA EOS program. The project is based on extensive field observations of water quantity and detailed chemical composition. It then uses remote-sensing driven models to try to explain the patterns observed in the field. Illustrations of the modeling component were presented in the IOW (summarized in Appendix 1). That is, CAMREX provides the “heritage” for this project.

The initial motivation for the “migration” of CAMREX to the Asia-Pacific region was stimulated both by the desire to test the Amazon construct on other regions simultaneous with the aspirations of the IGBP LOICZ Objective 1 on River Basin Inputs. A brief “idea” paper of what might be feasible on land-ocean interactions in SE Asia was provided to START in January 1996. Stimulated in part by this document, a pilot “test-of-concept” project was funded by the U.S. NSF/EPA Waters and Watershed program in 1996. This lead to the development of the “Version 1” model (described below). Further feedback was provided by the development of the “Integrated Science Plan” for Southeast Asia.

The overall topics represented here are part of the mandate of Southeast Asia START, both topically and as an integrating body. The initial linkage between the SARCS, SEA START RC and UW groups was formed at the July 1997 SARCS/WOTRO/LOICZ Workshop on Integrated Guidelines in Kuala Lumpur. A “statement of joint interest” was developed there (Appendix 2). Further discussions at the November 1997 Workshop on Greenhouse Gas Emissions in Chungli reinforced the idea.

The involvement of the APEC Internet Collaboration Center (formerly known as EduNet) with the UW and then SEA START RC came through the UW and marine resources in the Asia-pacific, and meeting between SEA START RC and the ICC team.

2.2. Current Project Elements

SEA/BASINS is now made up of several mutually-complementary elements, as respective funding sources. These include the Asia -Pacific Network (APN), START, USAID, and NSF, as well as complementary programs at SEA START RC, SARCS and the UW. The exact funding profile is discussed below.

3. Review of Primary Issues

The overall intention of *SEA/BASINS* is to take basic science information and translate it into several sectors focusing on capacity building and ultimately on water resource management at regional scales. To meet these objectives, it is important to work from a clear statement of what the component objectives are. Hence the IOW discussed the question –

3.1. What do we want and what are the issues relative to water resources and landuse changes in the region?

Four needs were identified as project foci:

- *Need 1. Tools for systematic synthesis of information leading to a coherent information base that can be applied to regional evaluation.* There is a large amount of data in the region, but little in the way of synthesis, tools to bring it together. It was recognized that while the focus here is on water, that the information is common to the linked gas emission and climate change agendas. As an end product, building a scaled modeling environment that addresses cumulative effects was seen as a very important product. Meeting this need requires that there be a systematic identification of what information is needed, then where is it and how it must be brought together.

- *Need 2. Predicative capability and, scenario generation* (across multiple time and space scales). While critical, synthesized information alone is not sufficient. The capability to then use that information to evaluate resource and policy options is critical. This must be done with models, and should include economic values , benefit/cost ratios for managers at levels of evaluating specific actions. For example, the Mekong River Commission has a very strong requirement for a robust drainage basin development plan (including land use control and population density).

- *Need 3. Process for communication among regional scientists, especially interdisciplinary, and proactive between scientist and policy; including visualization.* To bring together the multiple sources of information required, to analyze it with models, and ultimately convey to not only other scientists but to policy makers, is not a trivial nor commonplace task. It requires an explicit commitment to the process of communication and display. Solutions involve building capacity of interdisciplinary scientists (including recruiting young scientists trained in the tools of synthesis), developing for a for communications, and targeting how to involve policy makers. Technical issues of information communication and visualization must be incorporated in the process.

- *Need 4. Define Users*

The summary target is to develop integrated regional models, as essentially large-scale decision support systems for users, such as those in hydrology and sediment generation, water quality, hydroelectric power sectors.

3.2. Specific Applications

The tools developed in this process must be applicable to specific problems. For example, competition between water for upstream agriculture in the Mekong must be balanced against fisheries in the Mekong delta (including changes in Delta circulation). This translates into specific “science” requirements involving indirect and direct interventions in the hydrological cycle.

Key issues to be included

(1) *Indirect water routing*

Indirect impacts on the hydrological cycle and hence on water resources is due to:

- Change in land cover impact on hydrological cycle. Each landuse has its specific set of attributes; hence if pixel changes from one state to another, water flow is affected.
- Change in regional climate (such as CSIRO climate scenario model)

(2) Direct water diversion:

The most direct intervention in river flow is a dam, influencing both the amount of water available downstream and the chemical composition of that water (especially sediments). Currently there are 2 dams on the Mekong mainstem in China (with 5 planned). There are at least 5 dams on Mekong tributaries in Thailand, one in Laos, and one in Viet Nam. There are about 10 dams on the Chaophraya, one on the Red River, and a considerable number on smaller rivers. The Tonle Sap is regulated. To model the impacts of current and potential future dams, a key need is to know the function of the dam (relative mix of hydroelectric, irrigation, and flood control) and the subsequent operation rules.

Withdrawal of water for irrigation occurs both from reservoirs and directly from rivers. The most important irrigation need in Southeast Asia is for rice (differentiating irrigated and non-irrigated rain-fed rice). Cassava and other crops also have irrigation needs, but rice is dominant. Balancing impoundments and withdrawals, it is very important to maintain sufficient flow for wetlands, including floodplains; there are regions of agriculture and especially fisheries. Some immediate issues for modeling is the need to know where irrigation water comes from (including default is nearest upstream reach). Rice paddy water goes to evapotranspiration but also percolation (paddies ten to be well-drained; so infiltration function must be explicit).

Water is withdrawn directly for industrial and municipal use. This water tends to be returned "downstream" quite rapidly, but with significantly altered chemistry. Modeling this pathway in a Version 2 model will be difficult. It may be best to assume a simple function of population density (hence a data layer to be included).; e.g., "population density * 20 liters/day." (As a note, population data must be expressed per pixel).

(1) Changing water quality (dissolved, particulate); relative to certain baselines.

Water "quality," both in freshwaters and the immediate near-shore marine environments, is a very crucial problem. Consequences include impacts on fisheries, human health, and the cost of water supply.

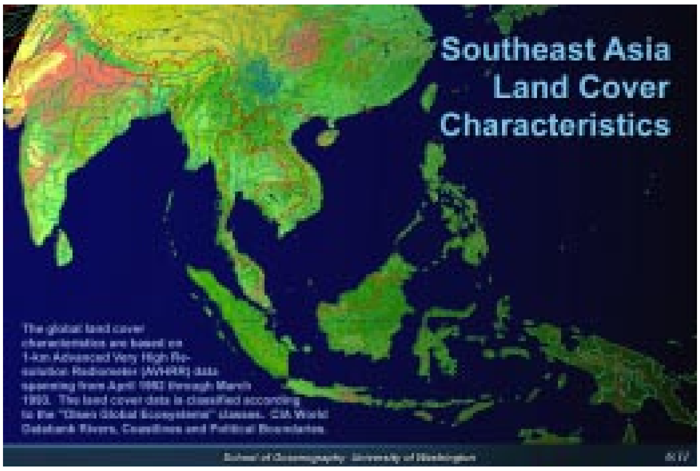
The primary pollution issues include general organic matter and nutrient (N, P, Si) loadings and specific contaminants.

- organic wastes (especially from municipal sources)
- N, P from fertilizer application and other agricultural/aquaculture practice
- domestic pollution (pathogens)
- industrial pollution (toxic chemicals)
- agriculture pollution esp. pesticides

The initial focus in this project will be on the organic matter and nutrients (contaminants tend to be site and chemical specific, and are less amenable to a regional approach).

4. Integrated Regional Model: Version 1

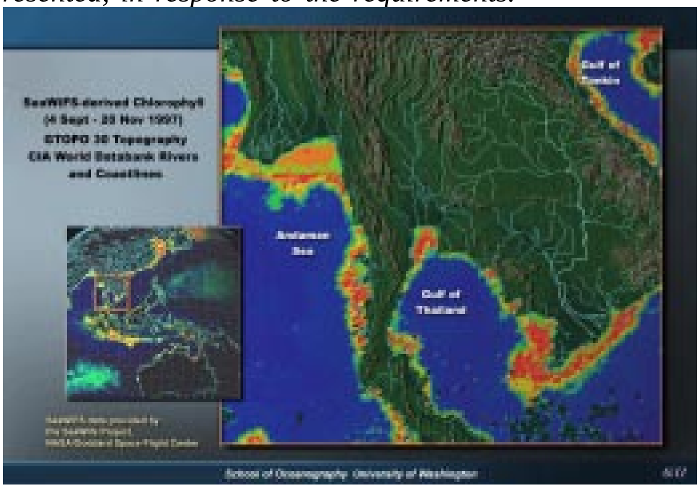
While the approach can be extended widely, the work to be accomplished here will focus on the region defined by the Irrawady to the Pearl on the mainland, and to New Guinea (recognizing that the smaller islands may not be tractable).The Version 1 of the model is summarized in Appendix 3.



5. Integrated Regional Model: Version 2

The intention with Version 2 is to move to a much more realistic representation of the drainage basins of SE Asia. This is made feasible by the recent release of new higher resolution data sets, and the project's ability to assimilate site- or basin-specific data for application, process model refinement, and validation. This is combined with the emergence of new satellite capabilities, which will be available in the lifetime of this project.

Accordingly, a detailed discussion was held on the requirements for and possible structural approaches for the Version 2.0, and is summarized in Appendix 4. In Section 4.1, the rationale for, and data and tasks are identified to make the Version 2 model "happen." In Section 4.2, a detailed model structure is presented, in response to the requirements. An immediate action issue is to "fill in the blanks of the task list."



6. Potential Regional Partners and November Workshop

The *modus operandi* for *SEA/BASINS* is to establish the core model structure APRN between SEA START RC and the UW, based on the above table, and then expand this core as a network of partners. The intention of the partners is to:

- Expand the capabilities and information represented in APRN by working with groups with knowledge and data on specific systems, as details and as validation
- Use the process of APRN as a capacity-building and training tool
- Reach policy makers

Hence the "ideal" network would be a cross-cut of representatives from specific sites, those with a broad range of process information or data sets, and institutions. Identifying and then involving potential participants will be an iterative process to "fill in the matrix". Partners will be expected to be active, participating not only in Workshops but also in lead-in and follow-up activities. The following table lists some potential partners in this project.

FOCUS	INSTITUTION	COUNTRY
Specific Basins		
Chaophraya and other Thai rivers	Royal Irrigation Department SEA START RC Chiang Mai University Walailak University	Thailand
Mekong	Mekong River Commission World Resource Institute	Cambodia USA
Irrawady	Department of Meteorology and Hydrology	Myanmar
Red and other Northern Vietnam rivers	Institute of Mechanics	Viet Nam
Southern Vietnam rivers	Institute of Applied Mechanics	Viet Nam
Pearl and other Southern China rivers	South China Institute of Environmental Sciences	China
Taiwan	National University of Taiwan	Taiwan
Philippines rivers	Philippines Atmospheric Geophysical and Astronomical Services Administration	Philippines
Indonesia	LAPAN	Indonesia
Laos rivers	Department of Meteorology and Hydrology	Laos PDR
Malaysian rivers	Department of Irrigation and Drainage Universiti Kebangsan Malaysia	Malaysia
Sepik		PNG
Multi-basin Interests		
	UNESCO East West Center/University of Hawaii Cornell University UNEP/GRID-Bangkok Australian National University	Indonesia USA USA Thailand Australia

Potential Users		
	Oxfam America Mekong Institute IUCN ADB USAID ESRI Co.	

As noted above, involvement in the Workshop implies carry-on interest. The objectives and tentative agenda for the Partners Workshop are the following:

Objective 1. Identify Partners who wish to become involved in the Project.
Objective 2. Use the “Internet Collaboration Center” (ICC) to establish a multi-individual and institution collaboration
Objective 3. Works during post workshop, incorporating new data
Objective 4. Present and Discuss model structure. Identify topic areas for work

Venue: Chiang Rai, Thailand

Agenda:

<u>Monday, November 16</u>
Arrive

<u>Tuesday, November 17</u>
Morning: Opening, Project Background, and Version 2 Model Basis
Afternoon. Case studies of individual basins
Evening. Reception

<u>Wednesday, November 18</u>
Morning. Working groups on data layers, with emphasis on scaling case studies to region
Afternoon. Working groups on modeling, with emphasis on application of regional to case studies

<u>Thursday, November 19</u>
Morning. Networking, data structures, and interactivity
Afternoon. Review and Tasks

7. Budgeting and Administration

The SEA START RC/SARCS/UW team submitted a proposal to the January 1998 competition . This proposal was subsequently awarded US$60,000, split between APN and START. The award was to cover two workshops (including preparation and follow-up) and capacity building. The NSF International Programs awarded $50,000 to the UW (for model development and training via the ICC distributed network). The Association Liaison Office of USAID awarded $100,000 for two years, in support of the networking activities. The exact profile for how these funds will be distributed by task is discussed below

Year 1: July 1998- August 1999

Source	US $	Covered		Timeline
APN	30,000	November Workshop	25,000	End of Feb 1999
		Capacity building	5,000	
		(note: if UW 15% overhead)		
START	30,000	July IOW Workshop:	8,000	End of Aug 1999
		Capacity building:	22,000	
ALO	100,000/2y	ICC Networking	5,000	
		Aug 99 Workshop	25,000	~2000
NSF	50,000	UW salaries		

8. Participants

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APPENDIX 1
THE "CAMREX" AMAZON HERITAGE

The overall goal of our CAMREX Amazon project is to characterize the spatial and temporal dynamics of the surface energy, water, and carbon cycles in the Amazon basin, and their links to the river network. The project is based on the integration of extensive field measurements, remote sensing, and modeling. The "Amazon HydroCASA," the basis for the modeling, is a set of spatially distributed raster models of the water and carbon balance on land, and then coupled the water balance to a simple river transport scheme which utilizes a digital river network representation that results from merging topographic and river network datasets. These models are forced at 5-km cell resolution by 9 years (1981-90) of monthly climate variables derived at the UW Remote Sensing Lab based on 9 years of daily radiance data from the NOAA-AVHRR satellites. They utilize spatial datasets of soil properties, topography, and land cover which have been collected and assimilated into a GIS over the last 5 years. The hydrological model partitions rainfall into evapotranspiration and surface plus subsurface runoff. Predicted runoff is undergoing validation by comparing predicted river discharge to observations at a number of reaches in the Amazon and its tributaries. For the carbon balance, we are using a modified version of the CASA model (Carnegie-Ames-Stanford Approach; Potter et al. 1993). Its net primary production (NPP) component, a light-use efficiency model modulated by water and temperature stresses, has been extensively evaluated by our group (Mayorga and Richey 1998; Mayorga et al. in prep; Mayorga in prep). We also have started to work with the litter and soil organic matter component.

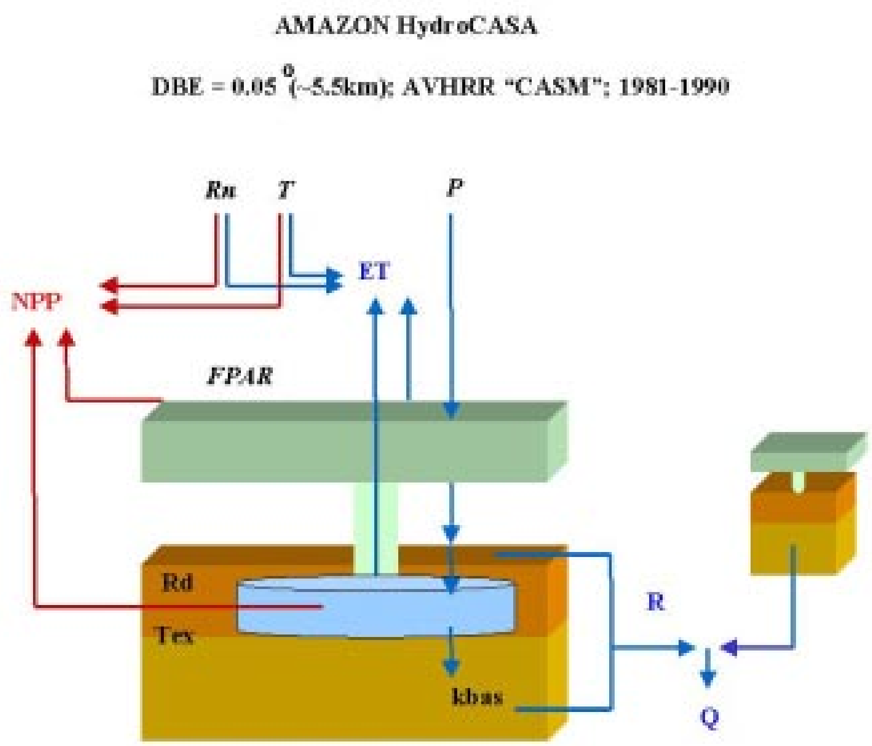


Figure 1.1 Schematic modeling diagram for Amazon HydroCASA Model

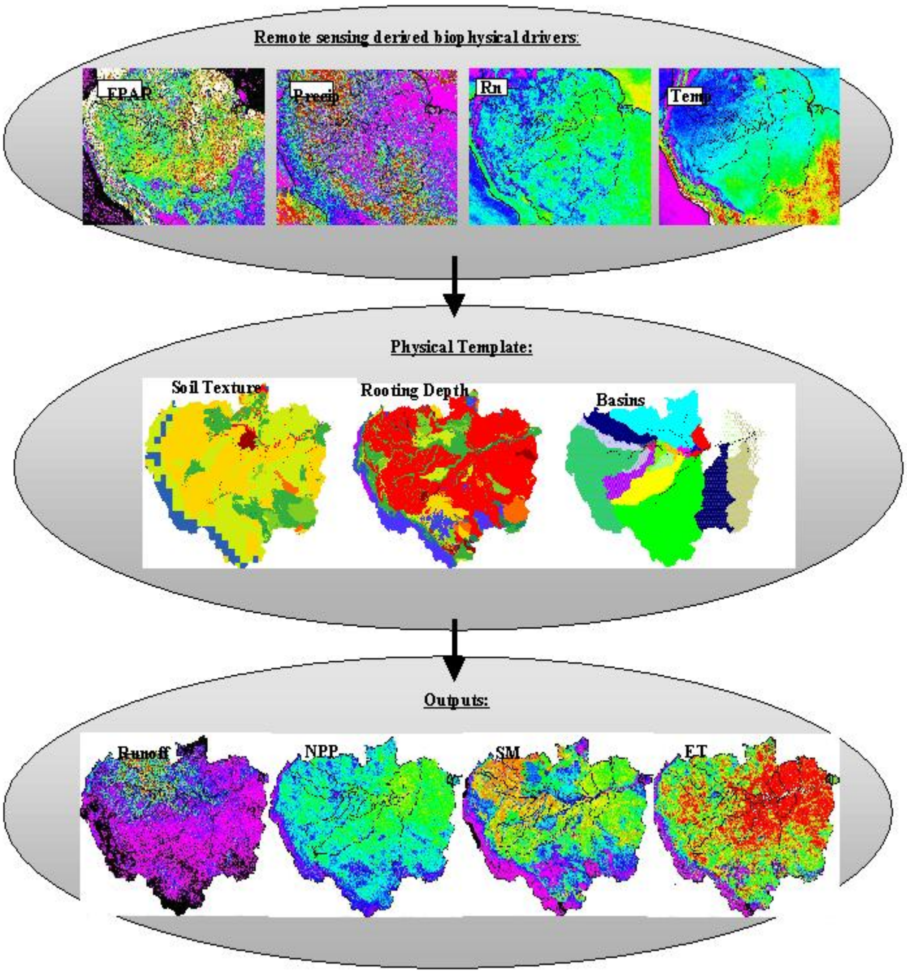


Figure 1.2 Representative parameters for Amazon HydroCASA (for August 1986). FPAR, precipitation, solar radiation and temperature are derived from a remote-sensing time series. As inputs to the physical structure of the basin (the physical template), outputs of runoff, NPP (net primary productivity, SM (soil moisture) and ET (evapotranspiration) are calculated.

APPENDIX 2
INTEGRATED REGIONAL MODEL OF RIVER BASINS OF SOUTHEAST ASIA
A Work Plan for Collaborative Research

The Importance of Regional-scale River Basin/Coastal Zone Dynamics in SE Asia

We propose to build an integrated regional model of the river basins of Southeast Asia. This model will have the objective of coupling hydrological pathways and biogeochemical indicators with the interactions and effects of human impact at the crucial regional scale to describe how materials are mobilized and transported from the land surface to the coastal zone. Our goal is:

*Goal**:** We will A) spatially model the biophysical and human processes within SEA drainage basins that describe the flow of water and impart chemical signals to streams and rivers ultimately entering the sea, B) develop GIS data bases at "fine" spatial scales (down to .05^{o}?) that the C) allow understanding and prediction of how human activity changes the basic processes and characteristics of rivers and their drainage basins, as expressed through integrated assessment modeling, D) carry the product through to policy makers.*

The rationale for this work is:

As humankind increasingly alters the landscape and the natural flow of materials through it, rivers have been among the ecosystems most severely impacted. The consequent impact on river systems occurs through erosion of the land surface and changes in the nature of the sediment and its associated organic matter and nutrient content from agricultural and urban sources. Changes in hydrology result as an immediate consequence of dam construction and large scale water diversion for irrigation and agriculture. Longer-term changes in regional weather patterns and climate will result in altered flow regimes. These current and future changes in drainage basin uses and characteristics result in major modifications in freshwater runoff, sediment transport, and the fluxes of carbon and nutrients to coastal systems. As fluxes from river basins change, they may significantly alter the metabolism, biogeochemical cycling, and the biogeomorphology of coastal areas. Changes in river hydrodynamics and flooding hazards coupled to direct changes in the morphology of deltaic systems have major consequences for economic opportunities and hence are risks for investments.

These issues are particularly acute in Southeast Asia. The extraordinary pace of development and population growth in the region has placed dramatically increasing pressure on river basins and their downstream coastal ecosystems. The scientific challenges faced in understanding these environments and how they will respond to natural and anthropogenic change are immense. While decisions about the usage and allocation of natural resources are generally made according to economic and political criteria, the sound management and optimization and hence sustainable use of water and land resources will require increasingly sophisticated information on the functioning of the physical systems and how they are affected by socio-economic and political institutions.

The overall problem, then, is to understand how water and its chemical load moves through drainage basins under different conditions, and how that movement is impacted by societal demands:

"What are the effects of changing land-use (and climate) on the mobilization of water and its dissolved and particulate load from the land surface into the coastal zone (at "regional" scales it is equivalent to the differentiating between "inputs from inland basins" and "direct coastal inputs")?"

The problem is to link the flow of materials through the landscape down river channels to the sea to the ecological and chemical attributes of basins. This must be done at scales much larger than the small watersheds typically studied, and it must be done in a quantifiable and ultimately predictable manner. It includes the requirement to assess short-distance direct inputs, including coastal cities, to the sea (an issue rarely confronted directly. The problem is to then interactively link that quantitative understanding to the demands put on that system by society and in turn the feedback onto society by changes in the system. Analyses must include time series, to understand the time scale of change. A final challenge is to convey the resulting information to policy makers and investors (perhaps through the utilization of enhanced visualization techniques).

Proposed Research

This work will be led by the Southeast Asia START Regional Center and the University of Washington, and will solicit cooperation from other interested parties. The specific work to be done will be based on merging and enhancing several ongoing efforts. The UW team has developed a detailed "Drainage Basin Element" (DBE) material balance and routing model for the Amazon, and is currently applying that model to Southeast Asia, using readily-available global data sets at a coarse spatial resolution (one degree). The team is investigating the application of newly-available data sets, including remote-sensing and elevation, to producing fine resolution results, particularly along coastlines. In addition to their other tasks in the region SEA START RC have been tasked with developing databases and networks of investigators in support of Global Change research in the region. Elsewhere, integrated assessment models are under development, which seek to link socio-economic actions with environmental actions. The UW team is starting to collaborate with the team producing the Asia-Pacific Integrated Model (AIM), which may provide a strong contribution to the work intended here.

Specific activities:

(1) Practicalities
i. Establish whatever formalities are required
ii. Establish communication modes: WWW (preferred "centralized"), FTP (default data exchange), SEA SPAN (cross-region information network), EduNet or ICC ("virtual" workshops)

(2) Review:
i. Current model structure and what is required to improve; especially with regard to "human-dimension" drivers, potential integration with AIM.
ii. Data requirements (multi-scale) for model structure and biophysical drivers: static, dynamic (including remote-sensing); focus on time-period
iii. Validation data: discharge hydrographs and chemistry data in the region
iv. Data currently available in SEA START RC system, identifying what is needed
v. Target what is required to fill-in holes

(3) Execution
i. Get required data
ii. Revise model structure
iii. Run model and evaluate output relative to validation data.
iv. Make model process interactive, transferable, and transparent to workers in the region
v. Publish round 1, set-up "future"

Development of the Working Model

How to define these linkages between regional-scale land surface processes and the capability of river systems to transport and process land-derived materials is a key issue. In practice, this involves development of large-scale river models. The central premise of a river basin model is that the constituents of river water provide a continuous, integrated record of upstream processes whose balances vary systematically depending upon changing interactions of flowing water with the landscape and the interplay of biological and physical processes.

Impacts of land-use change on an entire river basin cannot be defined by simply “summing up” the impacts observed on individual streams; extrapolations based on scaling must be made. Overall, we are attempting to recognize the spatial and temporal relationships between dynamic ecosystems within river basins, where a landscape is composed of ever-changing elements. These elements delineate relatively homogenous land units that transfer organic matter to the river system To address these inherent space and time scaling assumptions that must be made, we have developed a “drainage basin element” model (DBE), expressed within the modeling environment of the CASA biogeochemical model. Each DBE (“pixel”) is georeferenced within a drainage network and linked to data bases of basin characteristics (elevation, soil texture, vegetation types). The immediate requirements are to translate precipitation into runoff for each DBE, in a manner that allows estimates of residence time and flow though each element (to “mobilize” the chemistry), that water and its chemical load can be routed to the nearest stream and subsequently allowed to advect and react downstream.

Work Plan

Our ultimate goal is to combine basic research with assessment modeling in order to better understand, predict and constrain the effects of an altering landscape on Earth system health. Toward this goal, we propose to conduct a multi-national, multi-disciplinary, large-scale investigation into the processes that control and alter the health and activity of river systems within the Pacific Rim. This will involve

- construction of a GIS-based, process-oriented regional-scale routing model of river drainage basins using field-collected data and satellite imagery, and
- establishment of an integrated assessment plan for monitoring and predicting change in these and other systems.

This plan is a stepping stone in which basic scientific research on ecology, biogeochemistry, remote sensing and regional-scale routing are used to propel assessment modeling into a new dynamic arena. As we cannot achieve the ultimate goal alone, we have begun establishment of a cooperative international team of investigators from many traditional disciplines who are all interested in bridging the gap between science and policy.

(1) Construction of Spatially-explicit Drainage Basin Models.

We will examine the consequences of spatial scaling assumptions used in data structures on final model calculations. The emphasis will be on 1 degree data (~100 km) and the finer resolutions, operationally defined by what is available. A target is 4 km (or even 1 km).

We currently have the “coarse” coverage of South East Asia (at 1 degree) derived from the now-available global data bases (DCW, FAO, FAO, etc.). Increased resolution and a temporal dimension to these coarse grained static data sets may be derived from AVHRR

Pathfinder data sets. Once these data have been imported into the GIS structure, elevation data will be used to define the boundaries of the major basins. Then these basins will be used to “clip” through the attribute layers, with the intent of defining the descriptive characteristics of the respective basins (mean slope, soil texture, precipitation, etc.).

The second level of work is to define the regional mesoscale. To define the spatial topology (i.e., the relationships and interactions) of the drainage basin model elements, we must refine the coarse annual basin scale to the finer spatial and temporal resolution represented by the regional mesoscale. We will do this by first incorporating the USGS 30 minute digital elevation data to delineate the sub-basins of the respective river systems. Increased resolution of the data attributes will be derived from data bases currently compiled or that will be compiled by SEA START RC.

(2) Extension of DBE for South East Asia. The next problem is to define an approach for model synthesis that will produce hydrographs of water, sediments, and chemical species at the mouths of rivers of a region, a function of the attributes of the basin upstream. The first requirement is to introduce water into these drainage networks to produce the flow regimes that mobilize and transport the dissolved and particulate materials. Discharge hydrographs from the model will be compared to river gauging data, where available (such data are widely, but far from universally, available). We will acquire such data as they are available in the region. Data to drive the hydrologic model include rainfall, temperature, and solar radiation. We will obtain these data from various sources, including local meteorological services, outputs of regional climate models (which are being made available, including through the EOSDIS) We wish to emphasize here that the intent is to provide a means of calculating the flux of chemical substances from river basins; the intent is not state-of-the art hydrologic modeling *per se*.

The second task is to mobilize chemistry from the drainage basin elements. Each DBE is a volume with a mass of the element of interest distributed between soils, soil solutions, and in the drainage channels As the first approximation, the material that will be exported from the reservoir (DBE) can be represented as a mean concentration within the DBE. Then the flux out of the DBE is the runoff (calculated by the water balance model) times the function that represents how that mean concentration changes with time and attributes. Hence, the problem is to define the forms of the equations that describe that sequence. Once this has been done, and the "chemistry" transferred to the stream channel, it must be carried downstream, with in channel transformations and lateral exchanges accounted for. The key to this approach is that the model operates uniformly across regions, and is robust enough to reflect regional differences without tuning.

We will take the following approach to transferring this scheme to the South East Asia rivers. We will assume that the model equations developed for the Amazon at the start of this project (several months hence) are capable of describing DBE outputs throughout our (model) network. Results will be compared to data. These data will be derived from our selected field sampling and from existing databases (e.g., GLORI, local sources). Because the field data are used for verification, it is not necessary to construct detailed time series for each system (though such data are obviously welcome). The expected discrepancies between observed and predicted will be due to several factors. The first is that we have not adequately represented the processes at the DBE scale., and/or the downstream dynamics thereof. The second problem will be the confounding effects of landuse. We will have to separate these in an iterative manner.

Assembling and Utilizing Integrated Regional Models. The final step is to integrate the hydrological/biogeochemical modeling into an overall integrated regional model, which will include the interactions with societal demands. As stated above, once the basic "physical" model has been defined, the next problem is to integrate it with drivers from and back to societal demand. The immediate impacts on a river basin are manifest through the demand and supply represented by water withdrawal (for agricultural, domestic, and industrial uses), maintenance of biomass (fisheries), flood control, and hydroelectric demand. These direct factors are in turn mediated both by societal drivers (culture, wealth, population) and by institutional factors (administration, regulation/legal; which are not always directly linked to the societal drivers). Of course, reductions in water availability and quality will feedback onto the demand. A way to link these several systems is through integrated regional or assessment modeling. For example, Conway *et al*. (in press) use the IMAGE 2 model to evaluate water availability in the Nile basin under different scenarios of global, regional, and basin-scale forcings. IMAGE 2 consists of an energy-industry system (with 13 aggregations of countries), a terrestrial environment system, and an atmosphere-ocean system set of coupled models (Alcamo 1994). More specifically for South East Asia, Morita *et al*. have been developing the Asia-Pacific Integrated Model (AIM). We will base our initial activities on linking the physical models to the societal functions for water in the IMAGE 2 format. We anticipate that as we gain experience our approach will evolve rapidly.

Networking, Data Exchange, and Training

We propose to use this effort as a heuristic device to involve graduate students in the process of refining the structure of the Model with respect to the individual sites, and to provide loci for data identification and assimilation. We will do this by conducting virtual meetings and organizing task teams across the sites. The focus of the workshops will be to modify the model structure to the specifics of each site, and to target and acquire the data so required (and available). We will explore how to mesh remote sensing data with spatial models of land surface processes, and how to extrapolate in regions where data are sparse (most regions). We will examine how to include socio-economic and demographic information and drivers in a way meaningful to the geophysical fluxes, and how to make that information in turn responsive to resource assessment. A target of this effort will be establishing benchmarks of environmental data for the respective sites (and beyond). To do this, we will seek agreement on protocols for measuring and reporting. Pursuit of common database structures would facilitate comparative analyses. That is, we will be able to develop a prototype regional model that can be described in a single text that all parties can participate in developing mutually and electronically.

Concluding Statement

This proposal targets a large gap in the environmental sciences- regional-scale modeling of basic system processes with a policy-oriented eye. Such endeavors are by situation both critical to fill and difficult to handle. We believe that the microbial and biogeochemical indicators that we have successfully employed in other systems provide both the scope and breath necessary to evaluate the sources and potential fates of river borne organic materials in coupled land-river-margin systems at regional scales. Integrating such approaches into regional-scale modeling of river systems is a fruitful step toward understanding how systems operate and how our activities alter such systems. With this proposal, we will begin to collect that body of critical information for a variety of rivers in South East Asia, and to utilize our data to contribute to global river models which can then be tested and applied to issues of human impact and global change.

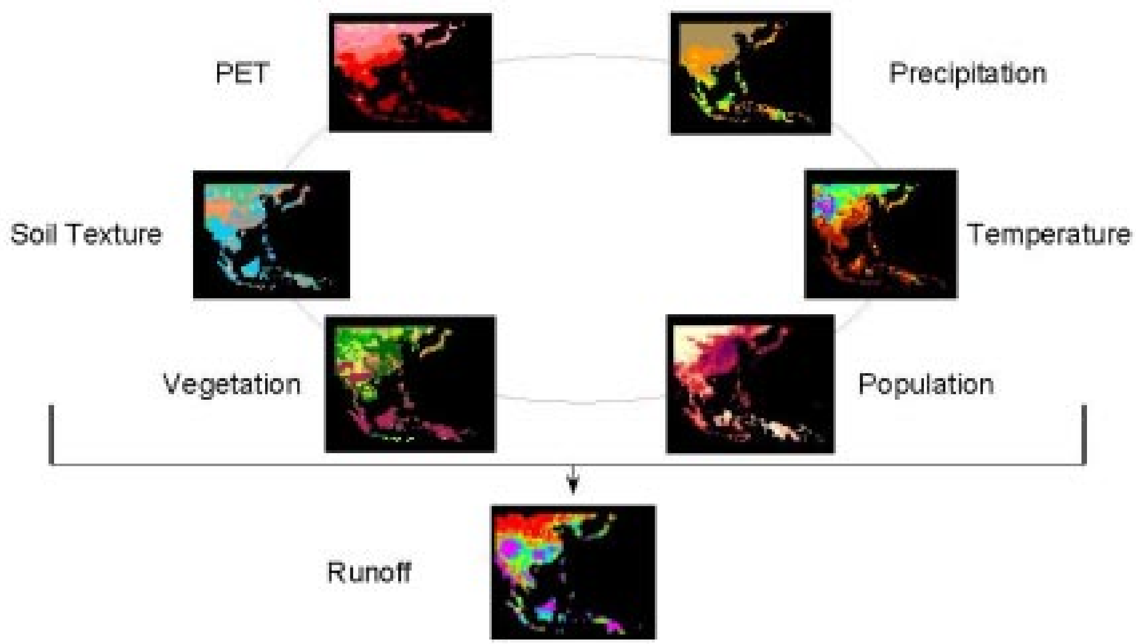
APPENDIX 3
NAGA Version 1

The extraordinary pace of development and population growth in Southeast Asia has placed dramatically increasing pressure on river basins and their downstream coastal ecosystems. The impact on river systems occurs through erosion of the land surface and changes in the nature of the sediment and its associated organic matter and nutrient content from agricultural and urban sources. Changes in hydrology result as an immediate consequence of dam construction and large scale water diversion for irrigation and agriculture. Longer-term changes in regional weather patterns and climate will result in altered flow regimes. These changes have major consequences for economic opportunities and hence are risks for investments. While decisions about the usage and allocation of natural resources are generally made according to economic and political criteria, the sound management and optimization and hence sustainable use of water and land resources will require increasingly sophisticated information on the functioning of the physical systems and how they are affected by socio-economic and political institutions.

The overall question we are addressing is:

"What are the physical and ultimately economic consequences of changing land-use and climate on the mobilization of water and its chemical load from the land surface into the coastal zone?

NAGA Version 1 (~ 100 km)



The problem is to link the flow of materials through the landscape down river channels to the sea to the ecological and chemical attributes of basins in a quantifiable and ultimately predictable manner. It includes the requirement to assess short-distance direct inputs, including coastal cities, to the sea (an issue rarely confronted directly). The problem is to then interactively link that quantitative understanding to the demands put on that system by society and in turn the feedback onto society by changes in the system. Analyses must include time series, to understand the time scale of change. A final challenge is to convey the resulting information to policy makers and investors (perhaps through the utilization of enhanced visualization techniques).

The overall objective of the work to be done in this project is to engage scientists, policy makers, students, and the private sector in developing and ultimately utilizing an "integrated regional model" of the river basins of Southeast Asia. This model will have the objective of coupling hydrological pathways and biogeochemical indicators with the interactions and effects of human impact at the crucial regional scale to describe how materials are mobilized and transported from the land surface to the coastal zone. We regard the development of this model as a sequential process, working with progressively finer levels of data resolution, as the data becomes available. Our "Version 1" was developed essentially at the one–degree (~100 km) level, commensurate with the availability of numerous data sources. While we recognize the limitations of this scale, it enables us to "get going" and gain the experience necessary to work at finer resolution. (our Version 2 is being constructed at a nominal 1 km resolution), based on the lessons learned here). Chemistry is represented by a simplistic model of the behavior of dissolved organic carbon. The Version 1 model is structured into 3 modules: a spatial model of the attributes of the drainage basins, hydrology and chemistry (dissolved organic carbon-DOC), and is run on a monthly time step:

Spatial Model

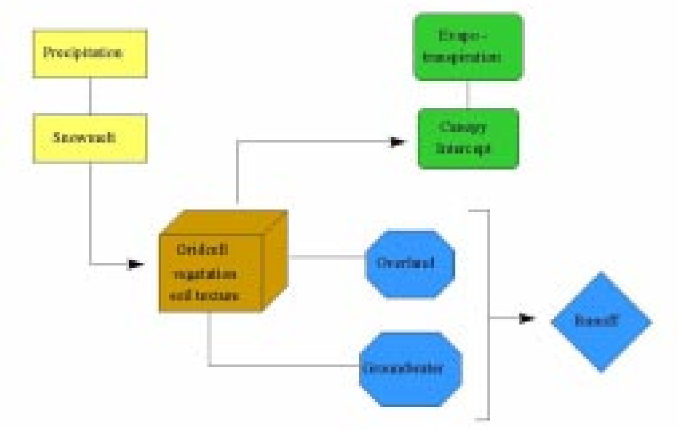
The relevant data themes were compiled into a geographic information system (Arc/Info GIS) in raster format with a 1degree gridcell size.

Attribute	Resolution	Source	Reference
Precipitation / Temperature	0.5 x 0.5 deg	IIASA	Leemans and Cramer 1990
Drainage Basins	5 x 5 min	GlobalARC	US Army CERL and Center for Remote Sensing and Spatial Analysis, Cook College, Rutgers University.
Potential Evapotranspiration	0.5 x 0.5 deg	GRID-Tsukuba	Ahn and Tateishi
Land Cover	1 x 1 km	EROS DAAC	Loveland et al. In press
Population	5 x 5 min	CIESIN	Tobler et al. 1995
Vegetation Type	1 x 1 deg	GSFC	Dorman and Sellers 1989
FAO Soil Texture	1 x 1 deg	GISS	Zobler 1986

		Texture						
		organic	coarse	coarse /med	medium	med / fine	fine	lithosol
Rooting Depth	Grassland&shrubland	1000	1000	1000	1300	1000	700	100
	Forest	2000	2500	2000	2000	1600	1200	100
Field Capacity	Grassland&Shrubland	200	141	200	354.9	352	340.2	27
	Forest	400	352.5	400	546	563.2	583.2	27
Wilting Potential	Grassland&Shrubland	91	63	91	171.6	200	250.6	13
	Forest	182	157.5	182	264	320	429.6	13

Hydrology

The hydrology of the river is modeled via a water mass balance for each grid cell within the basin; the model is a simplified version of the scheme we use for the Amazon basin.



$$Q_{cell} = P + SNOW - ET$$

Q_{cell} = Water runoff from a gridcell (mm/mth)
P = Precipitation (mm/mth)
SNOW = Snowmelt (mm/mth)
ET = Evapotranspiration (mm/mth)

The input is precipitation, and depending on if the temperature is above or below freezing, the precipitation is partitioned into rainfall or snowfall. Snowfall is accumulated in a snowpack until the averaged monthly T > 0 ^{o}C. During the first month, 10% of the snowpack is melted; this initiates spring melt. The second month of T > 0 ^{o}C and thereafter, 30% of the snowpack is melted. The snowmelt is directly contributed as precipitation to the gridcell.

The water-loss from the gridcell is divided into 2 pathways: evapotranspiration and discharge. The evapotranspiration is dependent upon the soil texture and vegetation cover of the gridcell. A fraction of the precipitation is intercepted by the vegetation cover, and it is assumed that all this precipitation is evaporated (canopy evaporation). A dataset obtained from UNESCO GRID-Tsukuba by Ahn and Tateishi utilized the Priestly-Taylor method to calculate the potential evapotranspiration (PET) from each gridcell. The Priestly - Taylor method gives a PET estimate depending on net radiation, air temperature, and air pressure. Actual evapotranspiration (AET) is calculated based on a fraction of PET, the soil moisture, and the soil texture. A texture dependent soil drying functions to scale the AET derived by Potter et al. (1993) is used here.

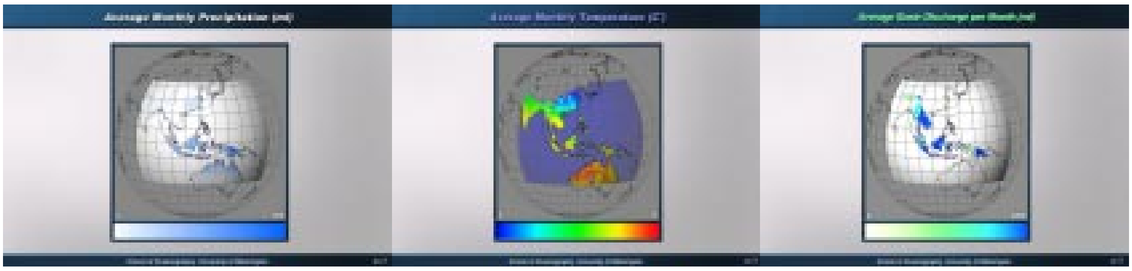
The runoff from each gridcell is divided into overland surface flow and groundwater flow. The overland surface flow is determined as a function of the saturation level of the upper soil compartment (Potter 1993). The groundwater flow is a function of the "bucket " volume i.e. the water holding capacity of the gridcell. Both the vegetation's rooting depth and soil texture determine the water holding capacity. The lower and upper limit to soil water content was assigned as the wilting point and field capacity, respectively.(Vorosmarty 1989, Potter 1993).

The groundwater aquifer is divided into 2 soil compartments. The soil water holding capacity is determined in the upper soil compartment. Precipitation input in excess of the capacity is transferred to the lower compartment. Groundwater flow is only allowed from the lower soil compartment. The amount of groundwater input to the river is determined by the following:

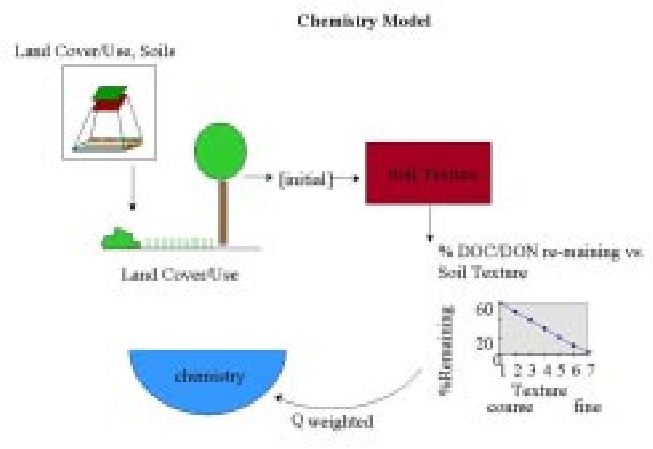
$$\frac{d\,sl}{dt} = D - kbas * sl$$

sl = water content in the lower soil compartment for time t (mm/mth)
D = amount of water draining from the upper to the lower soil compartment in time t (mm/mth)
kbas = soil conductivity (unitless)

Total river discharge is calculated by summing up all the groundwater and surface flow inputs from each grid cell within the river basin. It is assumed that all river inputs reach the river mouth within the month time step. Validation of the hydrology model is possible due to monthly discharge data from several rivers in the region. The data time series run from anywhere between 5 to 40 years. Data was provided by the Global River Discharge Center, Germany.



Chemistry



The hydrology output is now used in conjunction with the DOC, and a discharge weighted average DOC concentration is generated for each basin per month (note: the literature shows that ~70% of wet tropical rivers did not exhibit a relationship between discharge and DOC). Actual field studies on the chemistry of Southeast Asian rivers are few. The data necessary to carry out the traditional approach towards flux estimates are scarce and not present to the same degree necessary. Previous research on various geographic areas has determined consistent relationships between river chemistry and watershed characteristics (McClain, Howarth, Claire, Ludwig, Nelson, Hope, Fisher, Likens, Dahm, etc). The DOC model consists of a 2-step process. A DOC concentration corresponding to the upper soil layer (O-Hor) is assigned based on the gridcell's land cover. The land cover data is derived from Olson's Global Ecosystems classification (Olson 1994) which we simplified down into 19 classes. The removal of DOC in the soil column is simulated by removing a percentage based on the fineness /coarseness of the soil texture. The result is a DOC concentration for each gridcell in the basin.

A 2-step deterministic model to estimate the DOC flux from Southeast Asian rivers. First, an initial DOC concentration is assigned to the runoff from a gridcell based on the land cover. The concentration reflects the potential for DOC production by that land cover e.g. wetland areas will have higher DOC concentration than areas covered by bare rock.

Land Cover	DOC(mg/L)	Soil Texture	Soil Number	% DOC removed
Urban	10	Organic	1	65
Dry Crop	20	Coarse	2	55
Irrigated Crop	30	Coarse / Medium	3	45
Grassland	20	Medium	4	35
Shrubland	20	Medium / Fine	5	25
Savanna	20	Fine	6	15
Wetland	50	Lithosol	7	5
Deciduous Forest	40			
Barren	5			
Evergreen Forest	40			

Second, the DOC concentration is decreased based on the soil texture within the gridcell. The FAO soil texture classifications are arranged in order of increasing fineness. A linear function was fit between the texture and the percentage of DOC removed from the initial value. The products from the two modules are now brought together. The DOC concentration assigned to the gridcell is multiplied by the runoff to generate the DOC flux. The individual gridcell fluxes are summed up over the river basin for the total basin DOC flux. An averaged

DOC concentration for the river basin is also determined by dividing the DOC flux by the basin discharge.

<u>Model Results: Observed vs. Predicted</u>

The hydrologic results indicate that the model better predicts the discharge of larger rivers (5^{th} order and greater) than smaller rivers. The Yangtze and Mekong River model results differ from the observed by 17% and 29%, respectively, whereas, the Irrawady, Sepik, Sittong, Pahang Rivers differ by 21% - 84%. We use a simple scheme and a 1 degree cell resolution to model the hydrology, and hence, are unable to capture the unique characteristics of smaller watersheds. With larger watersheds, the model is more likely to depict the representative basin characteristics.

The DOC model is structured upon 3 main premises: Land cover DOC concentrations are based on a literature derived mean values. Water entering the river channel has first passed through the soil column. Discharge fluctuations on a seasonal scale have negligible effect on DOC concentrations within the gridcell. Given these assumptions, the observed DOC correspond well with the model predicted DOC. The high DOC concentration predicted for Bang Pakong may be an artifact of the small basin size (comprises only 2 gridcells). The global averaged water discharge weight natural concentration is 5.75 mg/L and the most common natural concentration is 4.2 mg/L (Meybeck 1993). As the average DOC concentrations for SE Asia is close to both of these values, 5.7 mg/L, human impacts within the watershed appear to exert a negligible effect on DOC. If human impacts, such as sewage inputs, are occurring extensively in SE Asia, then these rivers exhibit high self-purification abilities.

APPENDIX 4
Toward *NAGA* Version 2.0

4.1. Data and Task Requirements

TASKS Toward Regional Model Version 2	Responsibles	*Actions*	*Time Frame*				
			Sm ’98	*F ’98*	*W ‘99*	*Sp ’99*	*Sm ‘99*
DEVELOP SPATIAL MODEL							
Current Status and problems: (1) Raw DEM from GTOPO30 (includes various non-uniform accuracy assessments) (2) Procedures to create a depressionless DEM (3) DEM-derived basins (4) Discrepancies between the DEM and DCW datasets (5) Defining Southeast Asia: politically vs. physically data (add New Guinea) (6) Resolving the issue of the DCW major rivers (7) Forcing consistency (8) Creation of the coastal zone (9) Believe vector in lowlands and DEM in uploads	Logsdon (UW)						
Drainage Network							
Complete burning of coastal DCW	Logsdon, Miller (UW)		x				
Cross-comparison with MRC 1:250000 images	Im (MRC) Logsdon, Miller (UW)	provide images validate	x	 x	 x	 x	 x
Improve resolution of river mouths/deltas (from 30 m DEM to 1:50000)	Anond (SEA START RC) Logsdon (UW)	Provide data Modify model	x	 x	 x	 x	
Higher resolution spatial data							
LUCC and other study sites *Update soils map from 1-Degree:Texture, chemistry, depths*	As desired						
Find and register higher resolution: from country maps, IGBP, IRRI etc	Moya and others	Find & register	x	x	x		

Validate with direct observation	opportunity						
Consider assigning by landcover for crops							
Land Cover/Use (ref. 1-km AVHRR-the only time series option relative to this project							
Concur on Projection Issues							
Select and validate relevant classes (insure attributes) Ho: Winchee	Moya, Snidvongs	validate classes	x	x			
Add population density and attributes layer(s) *fertilizer (as available) *water use (as available) *organic/BOD generation *etc	Snidvongs, Logsdon	Get & Use	x	x	x		
Construct "timeline": '00,'50,'90,'95,'00… Issue: How to get "alternate futures". (may need to encourage others to provide/develop "1-km 2000", "1 km 2020", etc.)	"Group"					x	
Embed and validate high resolution LUCC data 1985-95 time series, combined with socio-economic indicators (agriculture, forest, human settlement, water bodies, industrialization) Thailand (Chiang Mai-600000ha) Indonesia(Citarum-200000ha) Philippine (Magat-350000ha) Malaysia (Klang- 400000ha)	opportunity					x	
Climatology and Hydrology-goal: 10 days/10km/10 years							
Driving forces: Precipitation, Temperature, Radiation (construct fields as necessary) *Check regional sources and services *Check ECMWF, Global Precip Center (Aufenbach), etc. for monthly global precip (probably 1 degree)	UW, SEA START RC	Develop input fields	x	x	x		
Alternate scenarios: * CSIRO regional climate scenarios (John MacGregor)	SEA START RC					x	
River discharge at gauging stations: MRC, GRDC, national services, UNDP etc	UW, SEA START RC	Acquire, digitize and incorporate	x	x	x		

IMPLEMENT DYNAMIC MODELING							
<u>Hydrology Modeling</u>							
Water balance component, transition from 1 degree to 1 km	UW	Fine-tune					
Better routing schemes: *free-running (including steep & short) *dams (w/ irrigation, hydroelectric rules) *direct withdrawal for irrigation *direct withdrawal/return for municipal	UW	Implement		x	x	x	x
Run regionally/validate locally Consider: interface with detailed delta models	UW opportunity		x	x	x	x	x
<u>Hydrochemical Modeling</u>							
River chemistry data	SEA START RC, MRC, UW	Acquire	x	x	x		
Develop river chemical model	SEA START RC, UW		x	x	x		
Run and validate model						x	x
<u>Coastal Zone Dynamics</u>							
SeaWiFS Coastal Zone Ocean Color (note: land potential)							
1-km time series	SEA START RC, UW	Acquire, archive		x	x	x	x
Process (SeaDAS, IDL)	SEA START RC, UW		x	x	x	x	x
Consider: color partitioned as sediments, pigment, etc.	opportunity						
ESTABLISH NETWORKS: PEOPLE & COMPUTER							
Starting Point: UW, SARCS, MRC Models: UW Data layers: distributed	SEA START RC, UW	Workout details	x	x	x	x	x
Establish primary ICC links: UW-SEA START RC (MRC as feasible)	SEA START RC, UW	Setup	x	x	x	x	x
Resolve: What to migrate where when, relative to capacity							
Bring on New Partners/more resolved sites	Everyone							

4.2. Planned Structure of the Version 2.0 Hydrology (B. Nijssen)

will represent the land surface hydrological processes at a spatial resolution of 1 km. The water balance is calculated at each individual 1 km × 1 km grid cell, represented by the vegetation/soil column The combined surface and subsurface flow generated at each individual grid cell is routed to the stream network according to a travel time assumption. This travel time from grid cell to stream reach is a function of the path from the cell to the reach to which it drains. Once the water enters the stream reach, it is routed to the ocean through the stream network represented by the “stick” diagram. Water storage in reservoirs, and withdrawals from reservoir and channel reaches will be included in this routing model.

Following this conceptualization of the land surface hydrology processes, the Version 2.0 Hydrology Model can be divided into two major components. A “vertical” component,

which calculates the water balance at each individual grid cell, and a “horizontal” component, which routes the runoff generated by each grid cell to the ocean. This split into two separate components has a number of advantages. It separates the “indirect water routing” and “direct water diversions” mentioned in section 3.2 of the report. The former, which include impacts of land use change and climate change, express themselves mainly through the “vertical” model, that is, the water balance at the grid cell level. The latter, including increased withdrawals and diversions for agricultural, industrial, and domestic use, impact mainly on the “horizontal” model, which represents the flow routing. The separation into the grid cell and channel components, also allows for an easy interface to treat non-point source and in-channel chemical processes separately.

<u>Water Balance Model — Vertical Component</u>

The water balance model is applied at each individual grid cell, and separates precipitation (P) into evapotranspiration (ET), soil moisture change (ΔS_t), and runoff (Q):

$$\Delta S_t = P - ET - Q_t$$

where the runoff (Q) consists of a fast surface component (Q_f), and a slow subsurface component (Q_s). Precipitation can be intercepted by a vegetation canopy. After saturation of

canopy storage, the throughfall reaches the soil surface. Water reaching the soil surface can either enter the soil column, or contribute to surface runoff, depending on soil moisture conditions. A temperature index snow model will be used to represent snow accumulation and ablation processes. Snow melt is added to the canopy throughfall.

Most of the water balance model will be left unchanged from the Version 1.0 Hydrology Model, although some of the processes, such as snowmelt, will be parameterized differently to reflect the shorter time step and the higher spatial resolution. Particular attention will be given to an adequate description of paddy rice, which forms the major irrigated crop in South East Asia. Water for irrigation will be withdrawn from the appropriate reach or reservoir and added to the grid cell as throughfall. The default reach or reservoir for withdrawal will be the nearest upstream segment, since most irrigation schemes are gravity operated. The amount of water withdrawn will be a function of crop water requirements and water availability.

<u>Flow Routing Model — Horizontal Component</u>

As a consequence of the higher spatial resolution and the shorter model time step, the routing approach of the Version 1.0 Hydrology Model - summing the monthly flows generated by the 1° × 1° grid cells - , is no longer adequate. Instead, explicit flow routing will need to be included in the Version 2.0 Hydrology Model. The flow routing model consists of two parts:

1. Routing of water from the grid cell to the stream network.
2. Routing of water through the stream network to the ocean.

Routing from grid cell to stream network. Although a stream channel can be found in almost every 1 km^2 grid cell in the study area, it is impractical to develop a stream network which branches out to every individual grid cell. Instead we propose to represent only the larger rivers explicitly in our stream network. We will specify a constant source area (A_s) on the order of 10^2 km^2, or 100 grid cells, before channels will be represented explicitly. This means that no streams are represented explicitly in grid cells with a contributing area – or accumulation area – smaller than A_s.

Water will be routed from the grid cell to the stream network using a travel time approach. The travel time from each cell will be described as a function of the path from the grid cell to the stream reach to which it drains. This path will be determined based on the topographic gradient. The travel time can then be specified as a function of path length and slope. Initially routing from the cell to the stream network will be done as a simple translation, with runoff generated at

cell [i,j] at time t entering the corresponding reach at time $t + T_{i,j}$, with $T_{i,j}$ the travel time. If needed, this approach can easily be replaced by a distributed unit hydrograph approach at a later stage. Instead of a straight translation, runoff generated at time t would not enter the reach all at once, but would enter over a longer period.

Routing from stream reach to ocean The river network derived from the Digital Elevation Model, combined with other sources such as the Digital Map of the World, will be split into separate reaches which are joined at nodes. This is illustrated in the "stick" diagram in Figure 1. Functionally the nodes can be separated into the following categories:

1. Confluence node - node at which two reaches join
1. Reservoir inflow node - node at which one or more stream reaches enter a reservoir
1. Reservoir outflow node - node at which a reservoir empties into a downstream reach
1. Monitor node - node which has no other function than to monitor the discharge
1. Auxiliary node - node to break a long reach to meet stability requirements

Some nodes can have more than one function. For example, each node can be used as a monitor node, since hydrographs can be obtained for every node. Inflows to each channel reach or reservoir consist of outflows from upstream reaches or reservoirs, as well as runoff from grid cells which drain to the reach or reservoir. Outflows from each reach or reservoir consist of inflows to downstream reaches or reservoirs, as well as withdrawals for agricultural, industrial, and domestic water use.

Flow will be routed through the stream network using the Muskingum-Cunge algorithm, which is an approximation of kinematic wave routing. To meet stability requirements, and to keep channel segments sufficiently short, the routing model will most likely operate at a shorter timestep than the water balance model. In that case the runoff generated at the individual grid cells will be fed gradually to the stream reaches. Withdrawals will be spread in a similar manner. To simulate reservoir operation, assumptions will be made concerning the operation rules, depending on the main purpose of the reservoir, that is, irrigation, hydro-electricity, or flood control. These default operating rules can be replaced by actual operating rules if available.